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A NEW CONCEPT OF A LOW COST INTEGRATED STEELWORKS FOR EMERGENT COUNTRIES

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A NEW CONCEPT OF A LOW COST INTEGRATED STEELWORKS

FOR EMERGENT COUNTRIES

by

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INTRODUCTION

1. The numerous processes by which iron ore may be converted to any of a wide range of steels must necessarily be matched to particular conditions at the steelworks site. In this Paper the special needs of an emergent country which is establishing ab initio a steel industry have been examined. To give verisimilitude to this study, conditions have been assumed which often arise in practice; amongst the most important of these is that capital expenditure is reduced to a minimum. On the basis of assumptions, which are listed in Appendix I, a complete integrated steelworks has been designed which can produce an output of 100,000 tonnes of billet per year.

2. At the start of this design, it was necessary to understand clearly the present and future needs of an emergent country starting to produce its own steel. It would have been possible to propose a list of ingenious but commercially unproven methods of iron and steel making, the inventors of which claim substantial cost reductions, but it is our firm belief that an emergent country should not be saddled with the doubts and teething troubles which inevitably accompany these ideas when they are first applied. The older proven methods meanwhile grow in refinement under the continual economic pressure for greater output and higher efficiency. Perhaps the greatest virtue of the new ideas lies in their catalytic effect on the improvement of the older methods. The study has shown that providing the steelworks for an emergent country is tackled as an integrated design, a small works can be built which uses the basic constituents of the most modern commercially accepted iron and steel making practice with complete freedom for future expansion and refinement at a cost of about £90 ($250) per annual billet tonne. Whilst this figure is substantially less than for some recently built works of more than ten times the capacity, it must be realised that direct comparison is not valid since location, product requirements and in-built expansion capacity must be taken into account. Later in this Paper an attempt has been made to eliminate these factors and it has been shown that the capital cost per tonne of billet on the proposed small scale plant is 1.4 times the capital cost per tonne of billet resulting from an equivalent million tonne per year plant. This is regarded as a highly favourable capital cost ratio and has been achieved by simplification and by the increased use of manual labour on the small scale works to a degree which would not be possible with large scale operation. Inevitably the plant simplification has also resulted in some loss of operating efficiency on the small scale works.

3. Since the emergent countries have no readily available experience on which to draw, all equipment must be of the highest reliability and be capable of operation by unskilled workmen. Complete simplicity has therefore been a keyword in working for this. Designs - in particular the prestressed mill described - have been evolved which not only have a place in small low cost steelworks but which may be expected to make a profound impression in all future construction. Generally, electronic control gear has been omitted in favour of the use of some extra labour, but there is no reason why this refinement should not be added later should economics dictate.

4. A small steelworks of the kind proposed will be most needed in countries commencing a stage of economic expansion. The greatest demand is therefore likely to be for construction materials - that is, reinforcing bar, small structural sections, hexagons, squares, rounds and flats. The layout illustrated may however easily be extended to produce wire or at the other end of the scale, larger joists, channels and rails. Furthermore, by installing an electric melting furnace and a cogging press, suitable small outputs of alloy steels could be made. In spite of the simplicity of the equipment proposed, there is no reason why the quality of the product need be inferior to that from larger and more lavish steelworks producing a similar product.

5. Good coking coals are seldom readily available. It has therefore been assumed that in the basic plant a native low grade coke will be brought into the works from a local supply. If, as seems likely, there is no market for the by-products of coke-making, this supply could be produced by mechanised or, under some circumstances, simple beehive ovens. In some conditions it may be necessary to produce the coke on the steelworks site, and, in this case a mechanised beehive or alternatively a vertical slot coking plant could be built, the latter instead of producing rich gas by the usual regenerative system, would burn this gas internally. The exhaust from the coking plant could then pass to steam boilers and with surplus coke breeze, augment the locally generated electricity supply to a point at which the steelworks could become self-sufficient in generating capacity. This alternative system is envisaged as a possible future addition to the steelworks plant shown in fig. II. In the simple case when coke is brought into the plant from an external supply, there would be enough blast furnace gas to generate electricity in the works for the base load and thus essential services would remain operative and damage be avoided in event of a failure of the outside supply.

6. This study has shown that given reasonable conditions in material supplies, an enterprising emergent country could find ample economic justification for starting a steel industry, even of the very modest capacity discussed.

IRONMAKING

7. Theoretically, the chemical process of extracting iron from its oxides can be accomplished by less fuel than is used in the conventional blast furnace. There is also no reason why the fuel should have the physical properties of metallurgical coke or charcoal. The prospect of using a wide selection of cheap fuels has consequently spurred scientists to seek alternative methods of making iron. Recently more than one workable process has been developed but as yet these present no real challenge to the blast furnace except when unusual conditions tilt the balance in their favour. Typically they would flourish where coking coal or charcoal is unobtainable; where there is abundant cheap electricity; where there is natural gas at negligible cost or where special ore impurities occur or even where production requirements are too small for a blast furnace of economical size. These direct reduction processes must neither be disregarded, nor must there be an attempt to transplant them into an environment to which they are not suited.

8. Although the sense of converting coal to electricity at some 30% efficiency in order to supply heat to an electric reduction process may be elusive, if industry were concerned only with the isolation of iron from its oxide, by laboratory standards some direct reduction processes might prove the most efficient. But the issue is not so simple. In an integrated steelworks, modern methods of steelmaking use iron in the molten state; oxygen blown converters want hot metal with built-in fuel (carbon and silicon); regularity of supply and uniformity of analysis is needed. It is precisely these things that the blast furnace can provide. The suggestion that the carbon balance in the blast furnace is wasteful because fuel is used to bring the product to a liquid state and because the waste gases contain much of the fuel's energy, fails completely when the next stage of the integrated works demands that the metal must be molten and every heat unit in the waste gases is used to good purpose elsewhere in the works. Even slag, unlike gangue from some direct reduction processes, can be an asset as a by-product.

9. Other features stand to the credit of the blast furnace; it can feed upon almost any iron bearing materials; its construction can be simplified to a primitive form or elaborated to the last degree of automation; it requires no rare skill to operate, though skill must be acquired to achieve the best results.

10. Fuel may rightly be regarded as the key to the situation. Preferentially the blast furnace requires coke with a shatter index of about 90%. Nevertheless it remains a fact that a great deal of iron is made, especially in medium sized furnaces with coke of shatter index as low as 65%. Indeed charcoal can be used with advantage in moderate sized furnaces and even coal has been used in some districts, but it would be essential that it had certain coking propensities to prevent disintegration when carbonised in the furnace shaft. Recent innovations, in particular artificial

raising of the gas pressure, have gone far to overcome the irregularities of operation attributable to inferior coke. Likewise a significant proportion of the coke charge may be substituted by oil, gas or pulverized coal injected into the tuyere zone. Finally experiment may prove it possible to carbonise and briquette a local non-coking coal to provide a suitable furnace burden.

11. Beyond all doubt the orthodox blast furnace must be selected as the proven and reliable means of iron making for the emergent country with normal rather than unique conditions. Men of enterprise intent on establishing iron making in a new area, will not expect the chosen spot to be endowed with all the ingredients for success but they would be venturesome indeed if they put their faith in an experimental process rather than following the example of informed opinion throughout the world.

General description of plant

12. Fortunately a blast furnace is not seriously penalised by a restriction on initial capital expenditure. Basic plans can leave provision for all the elaborations which increased output and efficiency may demand whilst providing a furnace which may be simply and reliably operated from the start.

13. One important step in this direction would be to forego any attempt at ore beneficiation. Indeed the economics of attempting sintering, for example, on such a small scale are clearly shown in fig. I which gives the relationship between capital cost and processed quantity for a simple sinter plant. If the installation of beneficiation plant were postponed until the expansion of the steelworks gave economic justification, the exact requirements could be more accurately gauged. Meanwhile the furnace could quite well be charged with run of the mine material until the time was ripe for further investment.

14. With the advent of modern reliable refractories and gas cleaning, a major saving can be made by having two rather than three hot blast stoves. The precaution of holding a third stove in reserve because of occasional fouling of the brickwork by dirty gas is no longer justifiable since the associated risks have receded almost to vanishing point. These two stoves could raise the blast temperature to 800-850°C which is more than needed prior to the introduction of other refinements. The installation of a third stove at a later date would not only allow for the highest conceivable temperature to be reached but could also serve in a battery of five stoves supplying two furnaces, should a second become necessary.

15. For a long time it has been usual to equip a modern blast furnace with automatic means to screen, weigh and charge coke. The furnace proposed however would be of ample dimensions and would start by operating well within its capacity; thus the coke, like other materials, could be charged by the scale car. Automatic equipment would be fitted only when there was a greater demand for output. Following the same policy, the installation of equipment for high top-pressure operation and automatic stove changing would be delayed. Other refinements to follow later would be a passenger elevator to the furnace platform, mechanical slag notch stopper and power operated snort valve.

16. With an output of 100,000 tonnes of billet per year the amount of pig-iron required per day would be about 280 tonnes. However, occasional short duration stoppages of any furnace are possible in addition to the time required periodically for relining. Therefore the nominal rating of the furnace would be set at 320 tonnes of iron per day thus providing a small stock pile of cold iron to tide over operations in the remainder of the plant, or to be sold separately.

17. In its simplest form this furnace would consume about 1¼ tonnes of 22% ash coke per tonne of iron, i.e. 360 tonnes of coke per day. Experience might lead to an increase of driving rate to 400 tonnes per day with a consequent 10% increase in iron output.

18. It is not possible to generalise on the extent to which the furnace would benefit by pre-treatment of the ore, high top pressure, fuel injection, oxygen enrichment and humidification of the blast, but the object would be to reduce the coke consumption per tonne of iron. Thus if the blowing and coke burning rates of the furnace remain constant, the production of iron would increase as the coke per tonne decreased. It is quite conceivable that an apt combination of the above aids would decrease the coke consumption to 0.8 tonnes per tonne of iron, in which case the furnace output would reach almost 500 tonnes of iron per day.

19. Bearing in mind all these future developments, a blower would be needed to deliver 51,000 m^3/hour against 1.4 kg/cm^2 (30,000 c.f.m. against 20 p.s.i.g.) pressure or 42,500 m^3/hour against 1.75 kg/cm^2 (25,000 c.f.m. against 25 p.s.i.g.) pressure. Such a blower, which would be steam driven, could be expected to allow top gas pressure to be raised to between 0.35 and 0.5 kg/cm^2 (5 and 7 p.s.i.g.) at a later stage.

20. To handle an average of approximately 1000 tonnes of raw materials that will arrive daily, a system of furnace bins of one day capacity only would be connected to railway sidings by conveyor belts. Since material supply will essentially be irregular, buffer stockyards are also needed, into which the balance of materials can be fed by a single high line conveyor with throw off positions over the stock-piles. A mechanical shovel can be used both to spread the stock-piles and to feed material into a chute over another conveyor which recirculates it via the main incoming conveyor belt to the furnace bins. The capacity of this inexpensive substitute for the conventional stocking transporter bridge would be sufficient to meet initial requirements on a two shift basis. Three shift operation would later be introduced as the demand for output increased.

21. An electricity propelled scale car would withdraw material from the furnace bins to feed the furnace hoist. Operation of the skip by the scale car driver would be automatically interlocked with the bell opening and closing and distributor rotation to ensure a proper sequence.

22. Iron would be cast five times per day into rail mounted 60 tonne ladles with lids to conserve the heat, and be shunted to the steel melting shop. These ladles are cheaper than the more conventionally used mixers. Surplus iron would be sand cast into pigs or alternatively it could be granulated for easier handling and remelting.

23. It has to be recognised that iron production must temporarily cease after a period for furnace relining. A campaign normally lasts 4 to 10 years, after which the relining process can be completed in three weeks with meticulous planning. This lapse may be used for normal major periodic maintenance of the steel plant or alternatively the flow of production could be continued with stock-piled cold pig and scrap, if available.

STEELMAKING AND CASTING PLANT

24. The choice of steelmaking and casting plant will be substantially influenced by local conditions; nevertheless, two broad classifications exist. The process may be based upon the use of hot blast furnace metal or alternatively, upon steel scrap. Both these terminal conditions have been considered and in the case of the use of molten blast furnace metal, the integrated works has been assumed to operate on a closed scrap balance. Figure III shows the steelworks flow diagram.

25. Steel may be cast either by conventional methods into ingots which are then reduced to billets in a primary mill, or by continuous casting directly to billet size. These alternatives which result in approximately 30% and 16% scrap return respectively, have been compared in conjunction with each steelmaking process. The choice of steelmaking and casting methods must always be based upon both production and capital cost. However, it has been shown below that it is possible to combine low capital cost with an economically realistic production cost.

26. The alternative steelmaking processes using a feed of hot metal are reviewed as follows.

The Bessemer Process

(a) This process is thermally deficient with blast furnace iron of low silicon or phosphorus content and may result in a scrap build-up within the works. Furthermore, an inferior product is obtained which, whilst being suitable for reinforcing bars and small structural sections, could hinder the development of a wider range of products. The use of oxygen steam blast overcomes this problem of quality but a scrap balance could only be maintained by installing an electric melting furnace at extra cost.

The L.D. Process

(b) This method of steelmaking has developed rapidly in recent years because of its simplicity, low capital cost and high production rate. Normally sufficient heat is derived from oxidation to permit the melting of scrap arising from a steelworks based on continuous casting. Modifications such as lime injection allow a wide range of blast furnace metals to be treated. Oxygen is supplied to the converter which, in an integrated works without a piped supply, would be made in tonnage oxygen plant on the site.

The Kaldo Process

(c) This oxygen process is in some ways a more versatile method of steelmaking than the L.D. process. Much of the carbon monoxide is burnt within the converter and this results in high thermal efficiencies. Thus comparatively larger amounts of scrap or ore may be consumed. However, the furnace is mechanically more complex and refractory consumption is higher than in the equivalent L.D. plant.

The Open Hearth Process

(d) This is a most flexible process which accepts a wide range of charge mix. The slow driving rate and heat input affords good metallurgical control. However the furnace units are comparatively large and expensive. Cheap fuel is essential for economic operation and although oxygen can be used to increase output from a given furnace size, the cost of suitable oxygen plant is likely to be at least equivalent to any reductions in capital expenditure achieved on the steelmaking plant.

Comparison of the Processes

27. Within the confines of the assumed emergent conditions, capital and production costs have been worked out for the open hearth, Kaldo and L.D. processes, each operating with the alternatives of continuous casting and conventional casting into 20 cm (8 inch) square ingots. The basis of the comparison has been upon an initial output of 100,000 tonnes per year of cast product and the capital costs shown include all mechanical and electrical equipment, fully erected, together with the necessary ancillaries, i.e. lime kiln, tonnage oxygen plant etc. Services and transport costs are not included since they have been covered in a separate section. Information about the furnaces is shown in Table I.

TABLE I

FURNACE UNITS REQUIRED TO PRODUCE 100,000 TONNES OF CAST PRODUCT PER YEAR

Steelmaking Process	Furnace capacity Tonnes	Average cycle time Minutes	Minimum cycle time Minutes	No. of furnaces installed	Method of operation
Open Hearth (Normal)	60	480	450	2	Both working simultaneously on 84% furnace availability.
L.D.	10	47	25	2	1 working whilst the other is being relined
Kaldo	15	62	45	2	1 working whilst the other is being relined.

28. It is seen that in each case a margin has been left on the theoretical minimum cycle time. This is in order to make an allowance both for future expansion and for the use initially of unskilled labour. A minimum heat size of 10 tonnes has been chosen to give a reasonable production yield per cast and a simplified casting operation.

29. In order that the comparison of the different processes may be based upon similar products, in the case of conventional casting the cost of a primary mill has been included. The results of this comparison investigation are shown in Table II. In making a comparison between the conventional method of using ingot casting with a primary mill, and continuous casting, it must be remembered that the reduction of scrap recirculation from 30% to 16% achieved with continuous casting represents attendant operating cost saving in fuel, power and handling. In addition there is a capital cost saving in furnace size, services and shop space.

TABLE II

COMPARISON OF CAPITAL AND OPERATING COSTS OF ALTERNATIVE STEELMAKING AND CASTING PLANTS

Process	Capital Cost £m	$m	Production Cost shillings/tonne	$ / tonne
Open Hearth + conventional casting + primary mill	2.65	(7.92)	419	59
Open Hearth + continuous casting	2.01	(5.63)	284	40
Kaldo furnace + conventional casting + Primary mill	2.77	(7.75)	412	58
Kaldo furnace + continuous casting	1.62	(4.54)	276	39
L.D. furnace + conventional casting + primary mill	2.63	(7.36)	423	59
L.D. furnace + continuous casting	1.48	(4.14)	282	39

(Production costs include the cost of hot metal but exclude administration and amortisation)

(Capital costs are based on erected buildings and equipment but exclude civil engineering, transport and spares)

Selection of Process

30. The main factor in selecting a suitable steelmaking process for an emergent country must be the initial investment cost. Under the particular conditions chosen, the L.D./Continuous casting combination has been selected and the reasons are shown below.

(a) The combination represents the lowest capital investment per tonne of productive capacity.

(b) The grade of steel required can be produced at low cost with adequate metallurgical control.

(c) The relatively simple expedient of lime blowing enables high phosphorus irons to be treated.

(d) The furnace works on a short cycle producing small quantities of steel regularly. This is particularly desirable for a continuous casting process, producing billets of small cross section.

(e) A closed scrap balance can be maintained.

(f) Refractory consumption is low.

(g) A high yield of saleable product results.

31. Substitution of the primary mill by a continuous casting process is not only a direct cost saving but in addition, the works power plant capacity may be reduced.

Description of plant

32. The layout scheme, fig. II, shows a typical steelmaking and casting plant of this nature to produce 100,000 tonnes per year of 90-120 mm billets (3½ - 4¾ inch). With future widening of the works product range, billets of up to 180 mm (7.1 inch) section may also be cast in the plant described. Only one of the two 10 tonne converters shown would be operated at a given time whilst the second is being relined. The continuous casting plant consists of two single machines each employing a triple mould with space for a third machine. Expansion to 140,000 tonnes per year ou[illegible] can easily be achieved by operating the converters on the minimum cycle time of 32

minutes. In the layout, additional space has been allowed for a third 40 tonne converter which would be needed after the installation of a second blast furnace. The steelmaking and casting plant consists of three bays:- a hot metal and scrap charging bay, furnace bay and the continuous casting bay. There is a separate material stockyard together with adjacent lime kiln and tonnage oxygen plant. Scrap boxes are filled in the mill area and transferred to the melting shop by road and to the converter by crane. The converters are slagged into pots in this bay which is served by a 20 ton ladle crane and a 5 ton scrap charging crane.

33. The furnace and tapping bay contains the two converters, waste gas stacks, lances and control gear. Steel is tapped into a ladle from the furnaces and transferred by car into the continuous casting bay.

34. The continuous casting bay is parallel and adjacent to the furnace tapping bay and is served by a 20 ton high level crane. Steel is teemed via a stopper rod controlled tundish into the water cooled triple mould of the weybridge continuous casting machines. The billets are withdrawn horizontally from the machine on to roller tables where cut-off and parting torches prepare them before delivery to the billet stockyard.

35. A simple raw materials handling system is proposed and the conventional overhead bunker system eliminated. Boxes of the various additions are filled and weighed in an adjacent yard before transfer to the hot metal and scrap bay of the steel plant. From here they are lifted to the converter platform and charged by one of the overhead cranes.

Factors influencing the choice of steelmaking process

36. The choice of steelmaking plant will change if conditions other than those assumed exist. For example, if some quantity of external scrap is available at a favourable cost then careful consideration must be given to the Kaldo and Open Hearth processes. Fuel lances can be used to increase the scrap melting capacity of an L.D. furnace but this must be assessed in the light of the inherent low thermal efficiency of this operation. Such lances would however be used on the proposed plant when the blast furnace is being relined, as during this limited period lower efficiency operation would be acceptable.

STEELMAKING WITH 100% SCRAP

37. In areas where iron ore or suitable coking coal is not present, economical steelmaking is still possible based upon melting, either indigenous or imported scrap. Three alternative processes compete, all of which have a background of successful operation. These are electric arc melting, open hearth and the hot blast cupola converter process. The last two need small additions of cold pig iron charge for successful metallurgical operation but all three processes operate on a wide range of scrap grades. Either Kaldo or L.D. converters may be used with the cupola.

38. Unfortunately no clear guidance can be given on the selection of one of these processes. The choice depends greatly upon the availability and price of electric power, fuel and oxygen. For example, if cheap fuel oil or natural gas is available, then the open hearth process may well be competitive, whilst cheaper electricity obviously favours the electric arc melting method. The yields for the electric arc, open hearth and cupola converter processes are approximately 92%, 90% and 87% respectively. Table III shows typical capital costs for these processes together with the production costs, which it must be recognised may vary substantially under different site conditions.

TABLE III CAPITAL AND PRODUCTION COSTS OF STEELMAKING PLANT BASED ON SCRAP MELTING

	Cupola + L.D. + cont. casting		Cupola + Kaldo + cont. casting		Open Hearth + cont. casting		Electric furnace + cont. casting	
	£m	$ m	£m	$ m	£m	$ m	£m	$ m
Cupola Plant	0.75	2.10	0.75	2.10	-	-	-	-
Steelmaking Plant	0.87	2.44	1.01	2.83	1.2	3.36	0.53	1.48
Casting Equipment	0.67	1.88	0.67	1.88	1.02	2.86	1.02	2.86
Total	2.29	6.42	2.43	6.81	2.22	6.22	1.55	4.34
Production costs per tonne	343/-	$48.0	333/-	$46.6	353/-	$49.4	361/-	$50.5

(Production costs include a charge for scrap metal but exclude administration and amortisation)
(Capital costs are based on erected buildings and equipment but exclude transport and spares)

ROLLING MILL

39. In proposing a mill for an emergent country, the principal objective must be to design a relatively simple mill capable of rolling small quantities of a wide range of products to reasonably close tolerances. At the same time well prepared plans must be laid for future stage by stage expansion. This study of the conditions in an emergent country has shown that a conventional layout can provide an efficient and well-equipped mill which need not depend on highly skilled operators, and yet is well within the probable capital resources of an emergent country.

40. It is appreciated that in addition to the need for reinforcing bar and small sections, there is nearly always a strong demand for galvanised sheet, but this cannot be made as an economical proposition unless the output is considerably larger than practical from a works of this type.

Stage by stage development of the rolling mill

41. A suitable starting point for an emergent country and one on which the cost comparisons in this investigation have been based, would be to install a nine-stand combination bar and light section mill with a capacity of 100,000 billet tonnes per year. This mill would produce rounds, squares and hexagons of 10-15 mm (0.4-0.6 inch) section in straight lengths, as well as 35-75 mm (1.4 - 3.0 inch) angles and up to 75 mm (3.0 inch) channels, joists and flats.

42. In expanding the mill, the first need might well be for coiled rod of 6-10 mm (0.24 - 0.4 inch) section, the smaller size being suitable for wire drawing. At this stage, two-strand rolling could be introduced in the intermediate and finishing stands, which would increase the total output by between 25 and 30%. The smaller sections would then be passed to a six-stand rod mill for further reduction.

43. With growing industry in the country, heavier sections will come into demand. A third stage of development can therefore be contemplated in which a three-stand, three high, medium section mill would roll 15 m. (50 ft.) long channels and beams of up to 175 mm (7 inch) section, as well as 150 mm (6 inch) section angles, rails and fish plates. This addition to rolling capacity would enable the total works' output to match the iron output which might be anticipated from the installation of a second blast furnace. The output of this medium section mill will be so dependent upon programme, that rates cannot be pre-judged accurately in view of the frequent changes and short production runs over a wide range of sizes.

Description of the proposed rolling mill

44. By using a continuous casting process the expense of a breakdown mill has been saved. The billets for the bar mill would therefore arrive in the rolling mill section from the casting machine in 90 or 120 mm ($3\frac{1}{2}$ or $4\frac{1}{2}$ inch) square size of 3 or 5 m. (10 or $16\frac{1}{2}$ ft.) lengths. The medium section mill would accept 120, 150 and 180 mm square billets of the same alternative lengths.

45. Whilst 10 mm (0.4 inch) diameter rods could only be rolled in the proposed mill at a rate of about 12 tonnes per hour, with the sections over 18.5 mm (0.73 inch) the limit on output would be that of furnace capacity - that is 35 tonnes/hour.

46. The billets after dressing and inspection, are charged into a two-zone oil-fired re-heat furnace. Use of end charging and discharging can lead to appreciable cost saving, but it would be necessary to separate the billets manually. An adjustable hydraulic pusher would feed and discharge the billets to the furnace singly.

47. Roughing Stands Billets leaving the furnace area pass to a two-stand, three high roughing mill with roll size 470 mm diameter x 1400 mm long (18.5 x 55 inch). The billet enters the lower roll gap on the first stand and is raised to return in the upper roll gap by an automatic tilting table. It is then returned and positioned in the lower gap by an automatic drop guide. After four passes, the billet is sufficiently small to be guided by repeaters to the second stand.

48. Intermediate Stands From the roughing stands the bar is driven by pinch rolls through a transfer tube. The front and rear ends are trimmed by a photoelectric controlled crop and cobble shear during transfer. Heavier sections which are too big to repeat, are transferred by roller table. The intermediate mills, which for large sections would complete the finishing pass, consist of two 370 mm diameter x 900 mm long (14.6 x 35.4 inch) three-high stands, and one 430 mm x 600 mm long (16.9 x 23.6 inch) two-high stand, each fitted with repeaters for the smaller sections.

49. Bar Finishing Mill Sections below $14\frac{1}{2}$ mm (0.57 inch) are finished in two pairs of 288 mm x 480 mm (11.3 x 18.9 inch) two-high stands fitted with repeaters. A typical rolling schedule is shown for the mill in Table IV.

TABLE IV

TYPICAL ROLLING SCHEDULE

Stand No.	Pass No.	Area sq.mm. (sq.ins.)	Reduction %	Dimensions mm. (ins.)	Length metres (feet)	Speed m/sec. (f/sec.)	Time secs.
-	Billet	8100 (12.55)	-	90 sq. (3.54)	5 (16.4)	-	-
1	1	6340 (9.78)	22	-	6.44 (21.1)	2.6 (8.53)	2.48
1	2	4540 (7.04)	28	-	8.94 (29.3)	2.6 (8.53)	3.44
1	3	3320 (5.14)	27	57.6 sq. (2.26)	12.2 (40.0)	2.6 (8.53)	4.68
1	4	2160 (3.34)	35	-	18.8 (61.6)	2.6 (8.53)	7.23
2	5	1555 (2.41)	28	39.4 sq. (1.55)	26.1 (85.6)	2.6 (8.53)	10
1	6	1025 (1.59)	34	-	39.6 (130)	2.6 (8.53)	15.2
2	7	746 (1.15)	27	27.3 sq. (1.07)	54.4 (178)	2.6 (8.53)	20.9
2	8	522 (0.809)	30	-	78 (256)	2.6 (8.53)	30
3	9	397 (0.615)	24	19.9 sq. (0.78)	102 (334)	3.4 (11.15)	30
3	10	294 (0.456)	26	-	138 (452)	3.4 (11.15)	40.6
4	11	235 (0.364)	20	15.3 sq. (0.60)	173 (567)	3.6 (11.8)	48
4	12	191 (0.296)	19	-	213 (698)	3.6 (11.8)	59
5	13	164 (0.254)	14	14.3 dia. (0.57)	248 (813)	4 (13.1)	62
6	14	132 (0.205)	19	-	308 (1010)	4.9 (16.1)	62
7	15	113 (0.175)	14.7	12.0 dia. (0.47)	359 (1177)	5.6 (18.4)	64
8	16	91.6 (0.142)	18.8	-	442 (1449)	6.9 (22.6)	64
9	17	78.5 (0.122)	14.3	10.0 dia. (0.39)	517 (1695)	7.85 (25.7)	65

Gear ratio for Stands 1 and 2 is 6.8 : 1 with 1200 kW installed power (A.C.)
" " " " 3, 4 and 5 is 3.54 : 1 " 800 kW " " (D.C.)
" " " " 6 and 7 is 2.5 : 1 " 350 kW " " (D.C.)
" " " " 8 and 9 is 1.82 : 1 " 350 kW " " (D.C.)

Note:- The mill motors installed are rated to drive the mills in the first stage of expansion to 140,000 tonnes/year when double stranding would be used. In the event of future expansion not being contemplated, the installed powers could be reduced to 520, 375, 185 and 185 kW respectively to produce 100,000 tonnes/year by single strand rolling.

50. Cooling Bed Finished material from either the intermediate or bar finishing mill is carried to the cooling bed on a high speed roller table fitted with electronically controlled flying shear for cutting to lengths suitable for the 50 m. (164 ft.) bed. At the end of the roller table the bars are pushed off on to a chain conveyor and transferred slowly across stationary skids to be discharged by gravity and collected in batches for shearing to length by a 250 tonne shear. In order that the shear may keep up with production, some multiple cutting will be essential but it is felt that this would be acceptable in order to save initial capital cost.

51. Whilst it is necessary to provide a cooling bed to handle the light merchant sections envisaged, a case may arise where there is a requirement for bar and rod only. Under these circumstances a cheaper solution would be to coil the product. This method, in addition to saving space and thus capital cost, would facilitate marketing of non-standard lengths and also reduce cutting loss to a minimum. The bars would pass through a roll straightener before despatch.

Development to produce small section rod

52. From the bar finishing mill 10 mm (0.4 inch) sizes would be further reduced to 6 mm (0.24 inch) in a six-stand 280 mm diameter x 480 mm long (11.0 x 18.9 inch) rod mill train driven through a multiple gearbox from one motor. With the installation of coilers at this stage, rods up to 30 mm (1.2 inch) diameter could then be coiled on one of four hydraulically stripped pouring reels capable of coiling up to 0.48 tonne. The coils would discharge on to a high speed flat conveyor which would deliver them in the horizontal position to a hook conveyor.

Mill for heavier structural sections

53. The heavier structural sections would be rolled in a medium section mill of two three-high stands 550 mm diameter x 1600 mm long (21.6 x 63.0 inch) and one two-high stand 520 mm x 1000 mm long (20.5 x 39.4 inch).

Pre-stressed stand design

54. The first pre-requisite of accurate tolerance control is a stiff, rigid mill structure. The most economical way of achieving this whilst reducing individual component sizes and weights is to pre-stress the load carrying members. Figures IV, V and VI show a mill design with this feature which has been simplified to the point where it can be fabricated from oxygen-cut steel plate. All three-high stands in the proposed mill area would be of this pre-stressed design, with a fixed middle roll and hydraulically balanced top roll, the top and bottom rolls being adjusted by wedges. The wedges themselves are driven by screws designed to have very small backlash so that the roll adjustment is positive and precise whether the rolls are being lifted or lowered. One advantage of this type of stand is that it permits the use of roller bearings. The stand components are bolted firmly together, giving a minimum of free surfaces in contact, hence mill spring is not increased unnecessarily as components bear down under load. It is felt that these advantages are most relevant in a mill which is to be operated by unskilled crews, since less reliance need be placed on previous experience for setting the proper mill gap to attain a given product thickness. Two-high stands would be designed similarly so as to have identical bearings and chocks, thus leading to simplification of the spares provision. In this case wedge adjustment would be provided on the bottom roll. Both the wedges on any one roll are operated simultaneously by a single screw, which in turn can be adjusted to level the rolls. Axial adjustment is provided by a winged chock and stud arrangement which can be seen in figs. IV and VI.

COMPARISON OF LARGE AND SMALL WORKS

55. In order that a comparison of the costs of the 100,000 tonne works may be made with one of larger output, designs have been prepared and cost analyses made of the three main areas - ironmaking, steelmaking and rolling mill for a plant producing a similar product and of comparable simplified design. With the larger plant it has of course been necessary to modify certain operations to account for the increased output, in particular materials handling equipment where manual and other simplified methods are no longer practical. The 1,000,000 tonne plant includes a medium section mill since this larger output would undoubtedly be reflected by a demand for a wider range of product.

56. The table below shows the cost comparison, based on erected buildings and equipment but excluding civil engineering, transport and spares costs. The ironmaking section excludes furnace blowers which are contained in the power station perimeter.

TABLE V

CAPITAL COST OF 100,000 - 1,000,000 TONNE/YEAR PLANT

	100,000 tonne/year	1,000,000 tonne/year
Ironmaking	£1,205,000	£ 5,600,000
Steelmaking	£1,482,500	£ 6,280,000
Rolling Mills	£1,168,500	£15,819,000
Total -	£3,856,000	£27,699,000

CONCLUSION

57. On the basis of the material and labour costs set out in Appendix IV, it has been shown that a steel plant using a blast furnace for iron making, L.D. converters for steel production, and a pre-stressed merchant bar mill, can produce finished products under the conditions likely to be encountered in an emergent country at a competitive all-in price. Throughout the present study the need has been borne in mind for future expansion, and provision has been made for the progressive increase in the output of the plant up to at least 200,000 billet tonnes per year.

58. It is realised that very wide variations exist in emergent countries' site conditions, and it is evidently impracticable to cover all possible combinations of circumstances in a Paper of moderate length. To simplify matters, the authors have therefore considered a favourable combination of circumstances, which are however not unrepresentative of those found in some countries. The assumptions used in arriving at cost data have been summarised so that those using the information in this Paper can assess its applicability to the particular circumstances with which they are dealing, and make any necessary adjustments.

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APPENDIX I

Summary of assumed material supplies and site conditions

(1) The chosen site is adjacent to a main road and railway, is flat and there is no space restriction.

(2) Soil bearing pressure is 2 tons per sq.ft.

(3) The supply of iron ore from a local site is ungraded but contains no lumps over 20 cms. (8") major dimension.

(4) The ore analysis on a dry basis is as follows:-

Iron	60%	Manganese	0.1%
Silica	0.8%	Phosphorus	0.12%
Alumina	1.8%	Sulphur	0.05%

The raw ore contains 5% moisture.

(5) Dolomite blocks can be delivered to site. No burning plant is necessary.

(6) Sufficient electricity supply is available to supplement works generated power.

(7) There is a township in the district, where living accommodation for employees can be found.

(8) The mean temperature on site will be 25°C. Maximum temperature 45°C, minimum temperature 5°C.

(9) There is sufficient piped supply of settled unfiltered water from a local river which can accept some slightly soiled effluent downstream. Water solids content 25 parts per million.

(10) Coke is available delivered to site of equal or better quality than shown in the following specification:-

Carbon content	76.0%	Ash content	20 - 22%

(11) Limestone to the following specification is available locally:-

Lime	48% (85.7% $CaCO_3$)	Ferric oxide	1%
Magnesia	3% (6.27% $MgCO_3$)	Sulphur dioxide	2%
Alumina	1.5%	Moisture	3.53%

(12) Product specification:-

Carbon	0.1 - 0.15%	Phosphorus	0.06% maximum
Silicon	0.1% maximum	Sulphur	0.06% maximum
Manganese	1.2% maximum		

APPENDIX II

ASSUMED COSTS

Materials	Iron ore	£ 1. 5. 0. per tonne	($ 3.5)
	Boiler oil	£ 8. 10. 0. " "	($ 23.8)
	Coke	£ 4. 17. 6. " "	($ 13.7)
	Scrap	£12. 6. 0. " "	($ 34.5)
	Limestone	£ 1. 6. 0. " "	($ 3.6)
	Burnt dolomite	£10. 11. 0. " "	($ 29.6)
	Electricity	0.8 pence per kWh	($ 0.0093)

Labour Rates

Civil engineering and erection costs have been based on United Kingdom prices. It is felt that this will give a reasonably realistic representation of actual costs for an emergent country where although individuals receive less, this saving is offset by a proportionate increase in the size of the labour force.

Production labour charges have been based on the following wages scales:-

Engineers:	£45 - £135 per month	($126 - $381)
Supervisory staff:	£15 - £50 " "	($42 - $140)
Skilled operators:	5/6 - 15/- per day	($0.8 - $2.1)
Unskilled labour:	3/6 per day	($0.5)

It should be noted that labour charges represent less than 10% of the bare production costs.

APPENDIX III

CAPITAL COSTS

Ironmaking Plant - including:

Blast furnace; refractories; three 60 tonne ladles; concrete bin system; gas cleaning plant; materials handling; plant erection. — Total cost - £1,205,000 ($3,374,000)

Steelmaking Plant - including:

L.D. steelmaking plant; continuous casting plant; lime burning plant; tonnage oxygen plant; refractories; ladles, cars, stands etc.; electrical engineering; buildings; services; erection. — Total cost - £1,482,500 ($4,151,000)

Rolling Mill - including:

Mill mechanical equipment; mill electric drives; buildings; amenities; reheating furnaces; oil storage; cranes for rolling mills and billet stockyard; electricity distribution; cables; lighting; miscellaneous mill operating equipment; roll and guide shop equipment; general maintenance equipment; inter-connecting services and pipe work. — Total cost - £1,168,500 ($3,271,800)

Overall Co-ordinating Services - including:

Site supervision and management; administration block; maintenance shop and stores; laboratory; transport equipment; blast furnace gas and air main; miscellaneous site equipment and services. — Total cost - £1,414,500 ($3,960,600)

Civil Engineering - including:

Site survey; earthmoving and site clearance; boundary wall and gatehouse; roads; railways; drainage; water services; site preparation for the main works areas. — Total cost - £1,364,000 ($3,819,200)

Note:- The above figure is based on the specified flat site conditions and is therefore a minimum cost.

Power Station - including:

Two 36,000 kg/hr. (80,000 lbs/hr) boilers and equipment; two 4,600 kW turbo alternators; two 850 m^3/min. (30,000 c.f.m.) turbo-blowers; water treatment plant; two 25,400 litre/min. (5,600 g.p.m.) cooling water pumps; timber water cooling tower; switchgear, batteries, cables, lighting; substation equipment; buildings. — Total cost - £1,033,500 ($2,893,800)

SUB-TOTAL FOR STEELWORKS

(including - equipment, buildings, erection and co-ordination services) — £7,668,000 ($21,470,400)

Additional estimated capital charges

Spares provision	£700,000	($1,960,000)
Transport (based on 10% of shipped equipment)	£660,000	($1,848,000)

TOTAL CAPITAL COST OF STEELWORKS £9,028,000 ($25,278,400)

APPENDIX IV

PRODUCTION COSTS (excluding administration, amortisation, also credit for gas and slag products)

	100,000 tonnes/year		1,000,000 tonnes/year	
Ironmaking	£ - s - d	£	£ - s - d	£
Ore 1.65 tonnes	2. 1. 3.	5.8	2. 1. 3.	5.8
Coke 1.125 and 0.3 tonnes respectively	3. 9. 8.	15.4	3. 10. 0.	10.9
Flux 0.65 tonnes	16. 4.	2.3	16. 4.	2.3
Labour	9. 6.	1.3	6. 0.	0.8
Maintenance	1. 18. 3.	5.4	1. 15. 0.	4.3
Total per tonne of iron	10. 15. 0.	30.2	8. 16. 7.	24.7
Steelmaking				
Blast furnace metal 0.9107 tonnes	9. 15. 10.	27.4	8. 0. 10.	22.5
Ladle loss 0.0091 tonnes	2. 0.	0.3	2. 0.	0.3
Steel scrap 0.164 tonnes	2. 0. 4.	5.7	2. 0. 4.	5.6
Materials additions	17. 8.	2.5	15. 0.	2.1
Operating & maintenance materials etc.	1. 1. 6.	3.0	13. 6.	1.9
Labour	4. 7.	0.6	3. 6.	0.5
Total per tonne of steel	14. 1. 11.	39.5	11. 15. 2.	33.9
Continuous Casting				
Liquid steel 1.064 tonnes	15. 0. 0.	42.0	12. 10. 3.	35.1
Operating & maintenance materials	12. 8.	1.6	10. 2.	1.4
Labour	1. 11.	0.3	1. 6.	0.2
Sub total	15. 14. 7.	44.1	13. 1. 11.	36.7
Less scrap credit 0.064 tonnes	15. 9.	2.2	15. 9.	2.2
Total per tonne of cast product	14. 18. 10.	41.9	12. 6. 2.	34.5
Rolling				
Billet 1.136 tonnes	16. 19. 6.	47.6	13. 19. 8.	39.2
Production materials	4. 5.	0.6	4. 0.	0.6
Fuel oil	5. 6.	0.8	5. 0.	0.7
Electricity	3. 0.	0.4	2. 6.	0.3
Labour	13. 0.	1.8	10. 0.	1.4
Factory services	4. 0.	0.6	3. 6.	0.5
Maintenance	17. 10.	2.5	15. 0.	2.1
Sub total	19. 7. 3.	54.3	15. 19. 8.	44.8
Less scrap credit 0.13 tonnes	1. 12. 0.	4.5	1. 12. 0.	4.5
Total per tonne of bar and reinforcing rod	17. 15. 3.	49.8	14. 7. 8.	40.3
Works Services				
General works service charge	1. 0. 0.	2.8	17. 6.	2.5
TOTAL PRODUCTION COST FOR BARS AND REINFORCING ROD ETC.	18. 15. 3.	52.6	15. 5. 2.	42.8

Notes:- Costs are based on equal yields for comparison purposes. In practice the larger mill would operate at approximately 92% rather than 88% yield. There would be similar changes in the steelmaking and casting processes, necessitating adjustment of the works mass balance.

APPENDIX V

It will be necessary to make provision for financing material stocks, work in progress, and various debts which might arise in the year following commissioning. A suitable provision would be about 25% of the value of the annual sales. (This figure being based on full output which would not necessarily be achieved in the first year of operation)

Under favourable circumstances the capital costs shown above are representative of the finances necessary to start a steelworks of the type described. Consideration should however be given to the following factors which could increase the capital requirement.

(a) An unlevel, badly drained, poor bearing surface or inaccessible site may appreciably increase civil engineering costs.

(b) It may be necessary to build dock installations to operate the works and a township to accommodate workers.

(c) Connecting links between existing and site road and rail services may be needed.

(d) Water may be in short supply, necessitating extensive and costly cooling, recirculation, and possibly reservoirs and pipelines.

(e) If an electricity supply is not available, some extra generating capacity may be needed to carry peak loads.

(f) There may be customs duties to pay.

(g) Inaccessibility of the site may increase transport costs.

(h) The client may have legal consultancy and management expenses.

(i) There may be a need for operator training and other technical assistance.

(j) All insurance requirements must be considered.

(k) Purchase of site and access wayleaves.

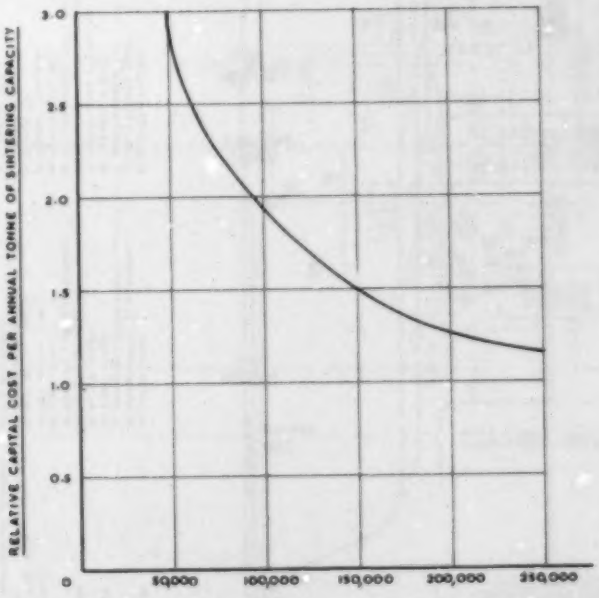
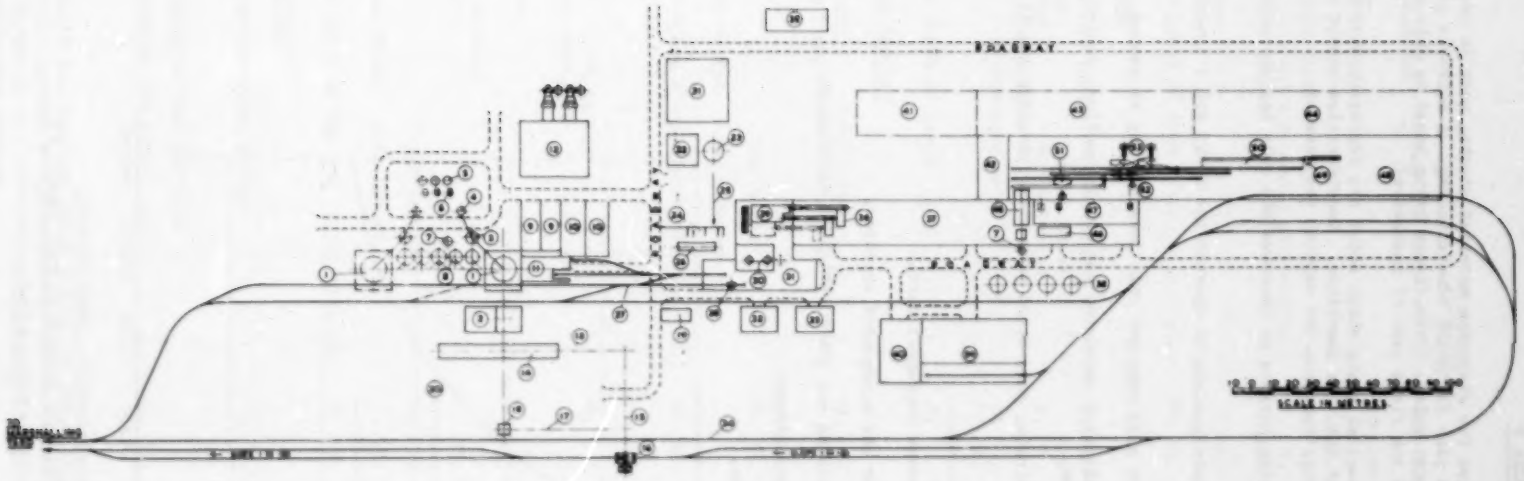


FIG. I THE EFFECT OF SINTER PLANT CAPACITY ON CAPITAL COST.



1. BLAST FURNACE.
2. ENGINE HOUSE.
3. DUSTCATCHER.
4. WASHING TOWER.
5. SEPARATORS.
6. DISINTEGRATORS.
7. CHIMNEYS.
8. STOVES.
9. FURNACE SLAG PITS.
10. MELTING SHOP SLAG PITS.
11. CASTING HOUSE.
12. POWER HOUSE AND FURNACE BLOWERS.
13. SCALE CAR TRACK.
14. HIGH LINE BUNKERS.
15. INCOMING CONVEYOR.
16. WAGON TIPPLER.
17. RECLAIMING CONVEYOR.
18. GROUND HOPPER.
19. LABORATORY.
20. RAW MATERIAL STOCKYARD.
21. INCOMING WATER POND.
22. PUMP HOUSE.
23. WATER TOWER.
24. LIME KILN BUNKERS.
25. RAMP TO LIME KILN BUNKERS.
26. LIME KILN.
27. HOT METAL LINE.
28. HOT METAL LADLE.
29. CONTINUOUS CASTING PLANT.
30. L.D. FURNACES.
31. MELTING SHOP.
32. GAS CLEANING PLANT.
33. OXYGEN PLANT.
34. RUNNING TRACK.
35. ADMINISTRATION BLOCK.
36. COOLING BEDS.
37. BILLET STOCKBAY.
38. OIL STORAGE TANKS.
39. MAINTENANCE SHOP.
40. GENERAL STORES.
41. FUTURE OPEN STOCKYARD.
42. FUTURE FURNACE BAY EXTENSION.
43. FUTURE MEDIUM SECTION BAY.
44. FUTURE COIL BAY.
45. REHEAT FURNACE.
46. SCALE PIT.
47. MOTOR ROOMS.
48. FINISHING BAY.
49. SHEAR.
50. COOLING BED.
51. ROUGHING MILL.
52. INTERMEDIATE MILL.
53. FINISHING MILL.

KEY
PLANT LAYOUT
FUTURE EXTENSIONS
ROADWAYS

FIG. II 100,000 TONNES/ANNUM INTEGRATED STEELWORKS PROPOSED SITE LAYOUT

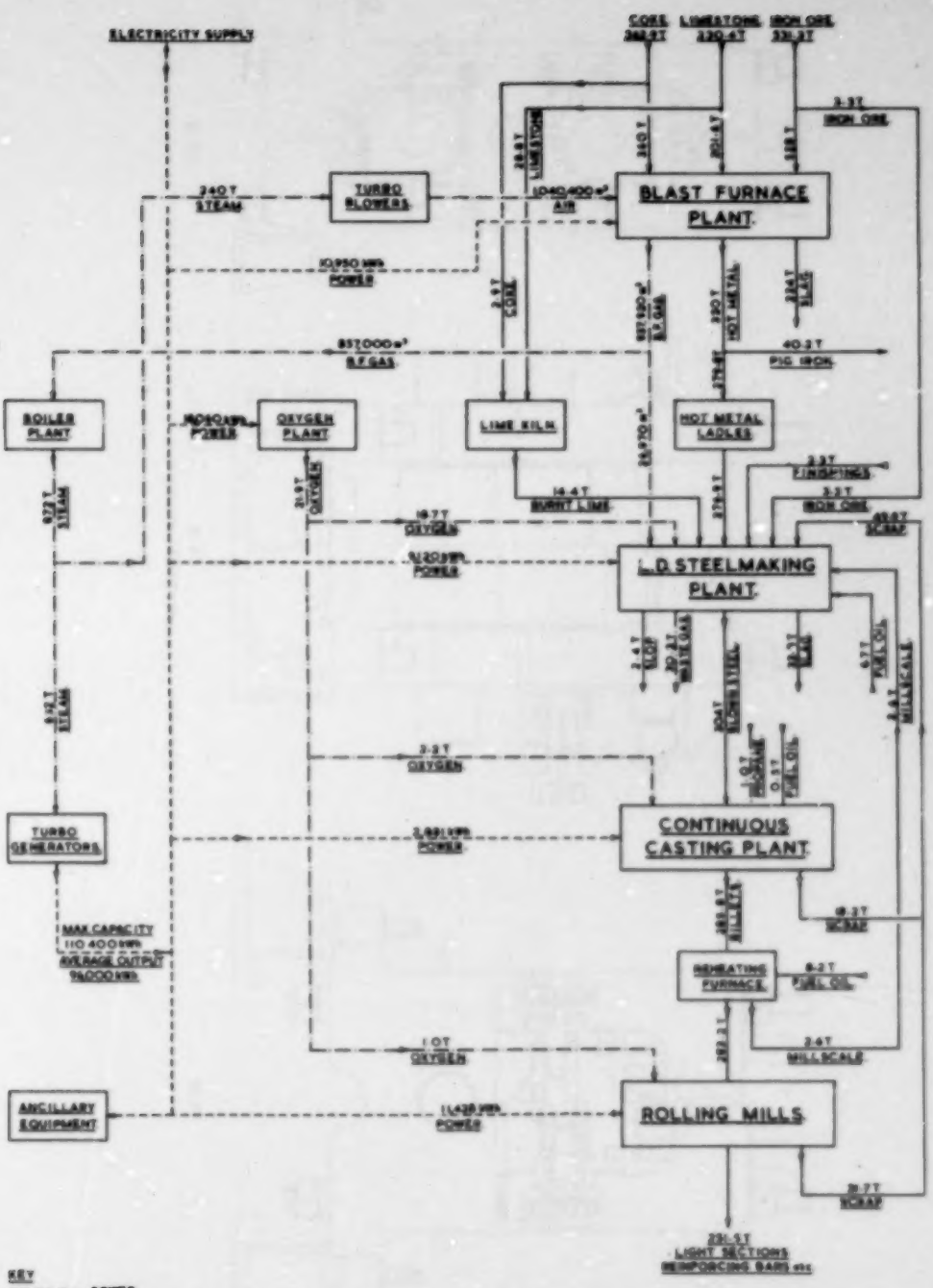


FIG. III FLOW DIAGRAM OF INTEGRATED 100,000 TONNES/ANNUM STEELWORKS. (DAILY BASIS)

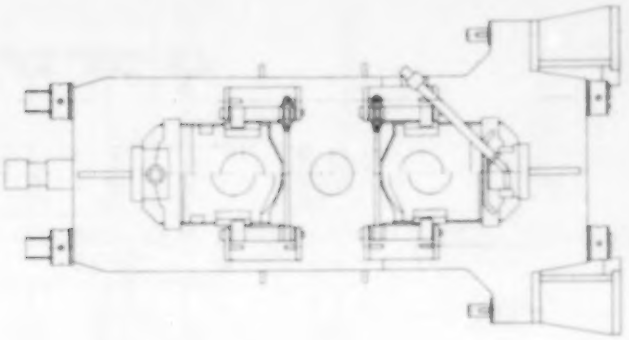


FIG III

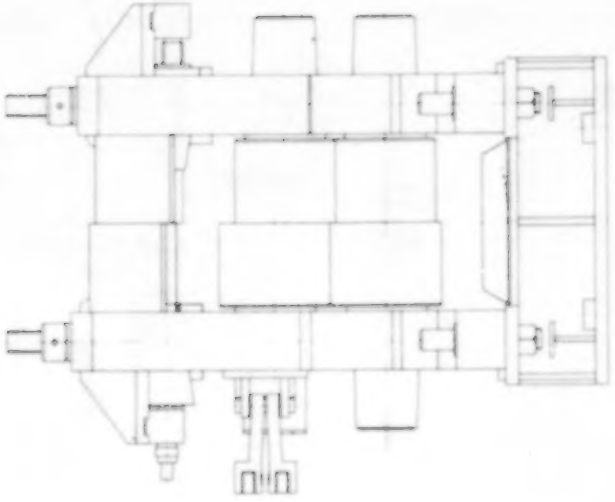


FIG II

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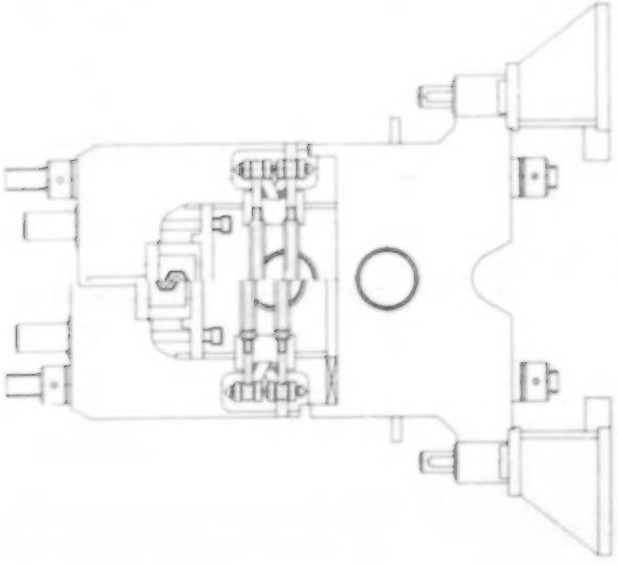

FIG I

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